Observations of Velocity Fields Under Moderately Forced Wind Waves

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LONG TERM GOALS

Long term goals are to observe and model turbulent transfer of momentum between the atmosphere and ocean in the presence of surface gravity waves. Surface gravity waves play a unique role in the coupling of wind stress into the ocean mixed layer as they gather wind kinetic energy and deliver momentum to the ocean interior through several poorly understood mechanisms, including micro breaking, full wave breaking and the transfer of wave energy into coherent circulation structures within the mixed layer. The resulting momentum transfers have both continuous stress components and highly episodic, strong events which significantly effect vertical distribution of kinetic energy dissipation and turbulent stress in the water column, complicating modeling of this important air-sea coupling process.

OBJECTIVES

The primary scientific objective of this project is to measure the turbulent stresses, shear and kinetic energy dissipation rates in the crest-trough region of wind forced surface gravity waves, and further down into the water column. Very energetic bursts of turbulent energy injected into this region of the water column by both microbreaking and breaking waves pass momentum and scalar fluxes deeper into the water column through poorly understood processes. It is crucial to measure these properties right up to the wave surface as micro-breaking and gentle spilling breaking events produce disturbances in the water column that change rapidly with distance from the wave surface, and are suspected to generate coherent rotational flows immediately below the wavy surface. Separating out small turbulent signatures from the large amplitude, mostly irrotational flow under ocean waves presents a significant observational challenge. Consequently this study is focused on moderately forced local wind waves, with 10m height winds ranging from 4-12ms^{-1} in ocean environments with low swell climates. Detailed near-surface observations over this range of wind forcing, which spans the transition into wave breaking, are being used to evaluate the role of competing momentum transfer processes in order to formulate improved parameterizations of wind stress transfer into the ocean mixed layer.

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14. ABSTRACT
Long term goals are to observe and model turbulent transfer of momentum between the atmosphere and ocean in the presence of surface gravity waves. Surface gravity waves play a unique role in the coupling of wind stress into the ocean mixed layer as they gather wind kinetic energy and deliver momentum to the ocean interior through several poorly understood mechanisms, including micro breaking, full wave breaking and the transfer of wave energy into coherent circulation structures within the mixed layer. The resulting momentum transfers have both continuous stress components and highly episodic, strong events which significantly effect vertical distribution of kinetic energy dissipation and turbulent stress in the water column, complicating modeling of this important air-sea coupling process.

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APPROACH

While many of the hypotheses for stress transfer under wind waves have been developed from controlled laboratory experiments, the approach taken here is to make direct, noninvasive measurements of the velocity structure under oceanic wind waves without the restrictions imposed by laboratory tanks. Field observations of sub-wave velocity profiles, 2D wave slope and local wave breaking have been made over differing wind and wave conditions at sites with minimal swell, to measure the response of the near-surface ocean to the wind forcing. In laboratory tank experiments phase averaging techniques, where nearly identical surface waves are propagated through the tank, allow turbulent motions to be separated from wave motions by ensemble averaging of the flow fields. Since this important analysis technique is not available in field observations under truly random wave fields, other techniques are being developed to identify turbulent momentum fluxes below the waves.

A unique high resolution Bistatic Coherent Doppler Velocity Profiler (BCDVP) developed in my research group at NPS (Stanton 1996, 2001, 2005a) has been used during the CBLAST experiment to measure 1.5 cm-resolution profiles of three component velocity vectors and backscatter levels over a 1.5m vertical span immediately below the water surface under wind waves. The bistatic geometry provides a small (3cm diameter, 1.5 cm high) sample volume, determined by the short acoustic pulse length and narrow transmitter beamwidth, to determine over-resolved 3 component velocity vectors and backscatter level at each range bin through the water column. This small sample volume is critical when sampling close to the highly curved wave surface (and resulting velocity field) immediately below wind waves. The continuous, dense profile of velocity vectors have allowed Reynolds stresses to be estimated through the water column in a surface-following coordinate system. A second, long-term observation of the water column was made with a 5 beam BADCP to study the impact of Langmuir circulations on the water column in the presence of both a wind-forced surface layer and a tidally forced bottom boundary layer.

WORK COMPLETED

Two field observations were successfully completed during the CBLAST Low Wind field program from July to December 2003.

The tide-following instrumented frame supporting the “wide base” BCDV velocity profiler constructed for this experiment, a five element short-base wave slope array, a surface imaging system, and a horizontal ADCP that resolved near-surface coherent velocity structures was deployed for 6 days under limited fetch wind waves with winds ranging from 3 to 10 ms^{-1}. This has provided a unique data set to investigate the transfer of momentum under waves. The BCDV performed well, but suffered marginal backscatter conditions during some of the light wind periods of the observation. Processing of selected hour-long sections of the data with has allowed sophisticated algorithms to be developed to correctly unwrap and resolve the three component velocity profiles for moderate forcing conditions (Stanton 2005b).

Data from a 5 beam BADCP deployed 20m south of the Air Sea Interaction Tower (ASIT) south of Martha’s Vineyard in 16m depth was recorded for three months spanning the fall of 2003. Continuous 0.5Hz sampled velocity profiles were measured with 0.5 m vertical bins from 1m above the bed to the ocean surface under winds ranging from 1 ms^{-1} to 18 ms^{-1}. The 5’th vertical beam of this system has provided high spatial resolution profiles of vertical velocity that are being used to detect and measure Langmuir cell properties as they advected past the bed-mounted instrument.

RESULTS

The five day short fetch deployment of the instrument frame shown in Figure 1a has provided a rich data set to study the velocity field under wind waves with onshore winds between 2 to 10 ms^{-1}. Wind forcing frequently changed abruptly during this period allowing the wave field and turbulence levels to be determined for a range of wave ages.

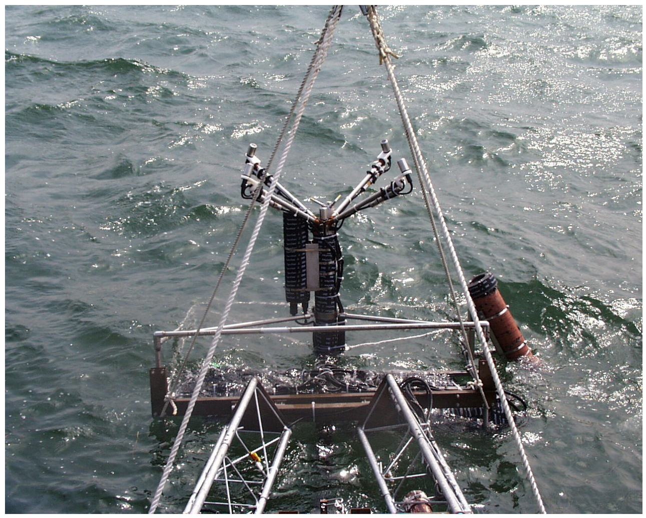

Figure 1. The BCDV velocity profiling instrument and surface imaging system being deployed during CBLAST. The instrument frame tracked tidal excursions, keeping the top of the BCDV 2m below the mean surface elevation.

Analysis of this data set is focused on velocity structures under moderate wave breaking conditions to estimate the vertical Reynolds stresses associated with discrete breaking events (Stanton 2004a, 2004b, 2005b). An illustration of the discrete breaking events seen during the observation period can be seen in the 100 second timeseries of acoustic backscatter energy measured by the BCDV, primarily responding to the void fraction of injected air-bubbles, in Figure 2b. Bubbles are rapidly injected to a depth approximately equal to the wave amplitude during the passage of a steep wave near t=7 seconds. Part of the bubble cloud is then entrained deeper into the water column by the coherent Langmuir cell seen in the low pass filtered vertical velocity profile timeseries in Figure 2c. By t=50 seconds, the entrained bubble population is being pushed toward the surface by the upwelling side of the Langmuir cell. A method to map stress, shear and scalar properties into a surface-referenced coordinate system is being used to estimate stress and shear production during these events, and reveal longer-lived coherent structures within the water column.

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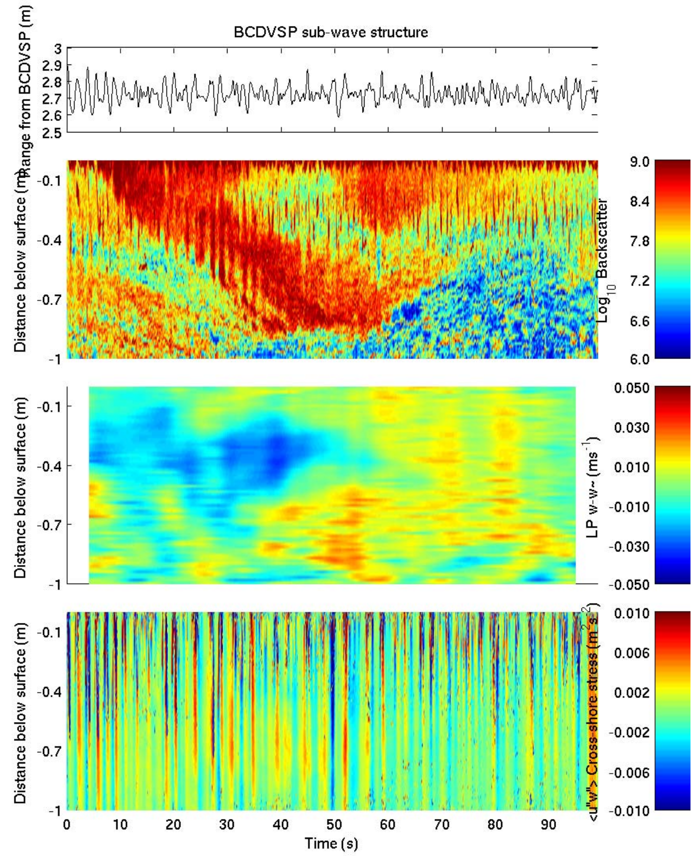

Figure 2. A 30 second profile timeseries of backscatter levels under short period wind waves shows bubbles injected during a wave breaking event at t=7 seconds, with a slow diffusion of the air bubble plume through the rest of the timeseries.

The effects of Langmuir circulation on the combined tidal-forced bottom boundary layer and wind forced surface layer are investigated in a recent MS thesis (Murat 2004), and manuscript in preparation. The high resolution vertical velocity and profile timeseries have allowed Langmuir cells structures to be detected, and circulation strength and scales quantified over a wide range of forcing conditions. In late fall, their contribution to homogenizing the deep, unstratified tidal boundary layer is assessed, and the scaling of their circulation intensity is compared with deep-water observations.

IMPACTS / APPLICATIONS

Improved observations of the processes responsible for stress transfer into the ocean wind momentum transfer into the ocean have broad application to air-sea interaction and gas exchange studies. Details of the vertical structure of this momentum transfer, including large coherent circulation structures in the mixed layer are important to correctly predict current shear and net circulation over the continent shelf. There is a clear need for improved drag coefficient parameterizations, in both atmospheric and oceanic models, particularly under light to moderate winds in very high resolution littoral modeling efforts including COAMPS.

RELATED PROJECTS

This research is closely coordinated with other CBLAST investigators including Jim Edson (atmospheric boundary layer), Al Pludemann (Langmuir circulations), and John Towbridge (mixed layer velocities). Comparisons of these data sets with LES modeling studies of surface layer turbulence and langmuir Circuations by Ming Li , Peter Sullivan and Jim McWilliams are in progress.

TRANSITIONS

A technology transfer is underway to commercialize the BCDV profiler to provide wider access to this technology.

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